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CARTRIDGE LEAK TEST PROCEDURES AT THE NAVAL ORDNANCE STATION, INDIAN HEAD, MARYLAND

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Naval Ordnance Station
Indian Head, Maryland

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The CAD Division Test Branch at the Naval Ordnance Station, Indian Head, Maryland, conducts cartridge leak tests in accordance with MIL-STD-331 (Test 118) and MIL-D-[illegible], to determine if any gas leak exists in the seal of a given cartridge. This report summarizes the theory and basic operation of the leak test equipment and details the procedures used at Indian Head.

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FOREWORD

A leak test procedure for determining gas leaks in cartridges of cartridge actuated devices has been developed by the CAD Division Test Branch of the Naval Ordnance Station, Indian Head, Maryland. This procedure is documented here. This work was funded under AIR Task A532-5322/163-6/4-0000000-18, Work Unit A53253-54/01.

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ABSTRACT

The CAD Division Test Branch at the Naval Ordnance Station, Indian Head, Maryland, conducts cartridge leak tests in accordance with MIL-STD-331 (Test 118) and MIL-D-21625 to determine if any gas leak exists in the seal of a given cartridge. This report summarizes the theory and basic operation of the leak test equipment and details the procedures used at Indian Head.

INTRODUCTION

Cartridges for cartridge actuated devices must be leak tested to determine if unacceptable leaks exist in the cartridge seals. This testing is conducted in accordance with MIL-STD-331 (Test 118) and MIL-D-21625.[1] MIL-D-21625 (paragraph 3.8.2) states that "The cartridge shall pass a dry leak test. Cartridges which exhibit a leak rate in excess of 10^{-5} cc/sec of air at a pressure differential of 1 ± 0.1 atmosphere shall be considered defective."[2]

The CAD Division Test Branch (Code 5013) at the Naval Ordnance Station, Indian Head, conducts these cartridge leak tests. This report summarizes the theory and basic operation of the equipment and details the procedures used by the Test Branch.

[1] MIL-STD-331 *Fuze and Fuze Components, Environmental and Performance Tests for*, MIL-D-21625, *Design and Evaluation of Cartridges for Cartridge Actuated Devices*

[2] A possibility exists that a cartridge with excessive sealant may give false readings on leak detector.

TEST EQUIPMENT AND THEORY OF OPERATION

Leak Test Equipment

The leak tester used by the CAD Division Test Branch is the Model MS-17UFT Ultra Fast Leak Test Station manufactured by Veeco Instruments, Inc.[1] The MS-17UFT Leak Test Station (Figure 1) is a sensitive and accurate helium mass spectrometer which indicates the flow of helium. In the center of the leak tester is a mass spectrometer tube (Cee-tube) tuned to detect the presence of helium and to produce an electrical signal proportional to the amount of helium present. An electrometer converts the amount of helium detected to a meter reading of cc · atm/sec of air A leak indicator box connected to the tester indicates the amount of cartridge leakage.

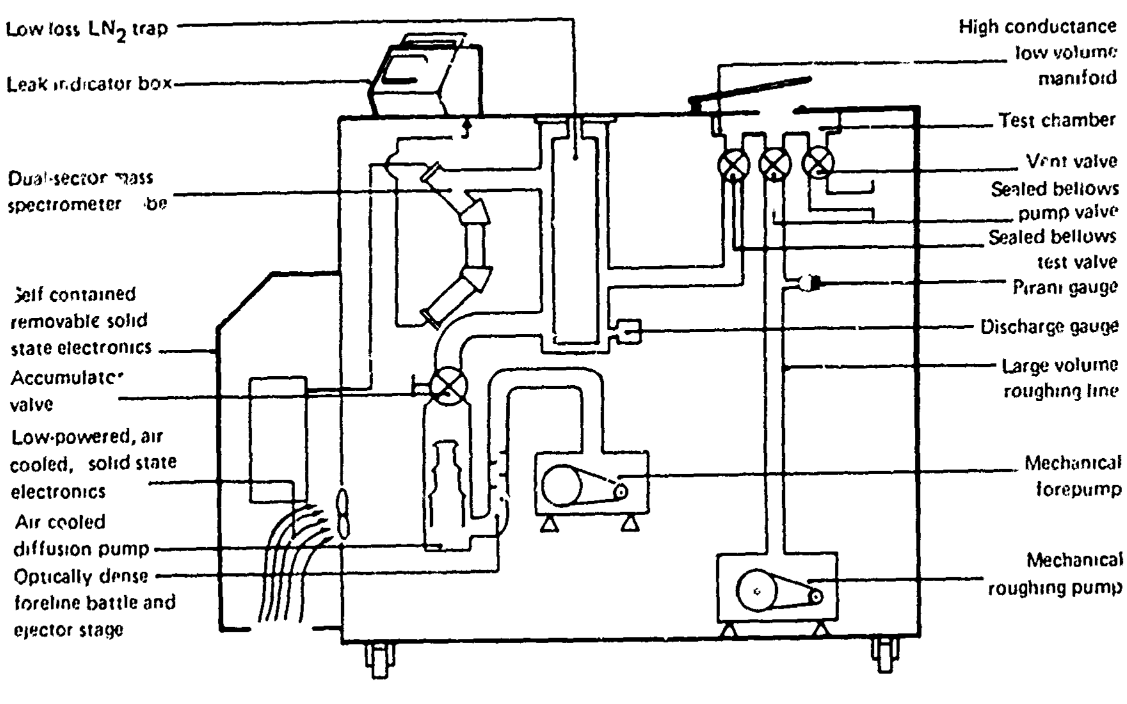

FIGURE 1. MODEL MS-17UFT ULTRA FAST LEAK TEST STATION

[1] Veeco Instruments, Inc Terminal Drive, Plainview, N.Y. 11803

The cartridge test cycle is divided into three stages: (1) pressurization of the cartridge with helium, (2) setting the leak point indicator on the leak tester, and (3) the actual cartridge leak test. If a cartridge leaks at an unacceptable rate during the pressurization, an amount of helium will be present in the cartridge. The amount of helium present in the cartridge which escapes under vacuum during the test and is picked up by the mass spectrometer will be higher than the leak point indicator and will activate a "leaker" light on the test set.

Theory of Operation

Pressurization:

Before testing with the MS-17UFT leak tester, a cartridge is placed in a canister which is pressurized with helium at 2 atmospheres for 1 hour. This pressurizing time is called the bombing time. If the cartridge seal has a leak, the helium gas will penetrate the seal until the pressure in the cartridge equalizes the helium pressure. Depending on the free volume of the cartridge, the bombing time, and the leak rate of the cartridge, the pressure in the cartridge may or may not reach the pressure of the helium gas. Each type of cartridge has a different free volume in the propellant chamber; therefore, the percentage of air to helium in the chamber will vary with each type of cartridge even though the cartridges may have the same leak rate. The cartridge free volume is considered in the leak point indicator setting on the tester. The leak indicator has a zero adjust control knob which adjusts the setting on the leak indicator scale. The larger the "negative exponential" setting, the more sensitive is the setting on the leak indicator scale. A more sensitive reading means that the leak detector can detect a smaller concentration of helium in the Cee-tube. The amount of helium in the Cee-tube appears as a visual signal on the leak indicator.

The cartridges are pressurized by the helium gas for 1 hour. This pressurization (bombing) time is one of the variables that determines the leak point setting of the instrument.

After pressurizing the cartridges for an hour, the canister is vented by opening the manual valve on the underside of the canister, and the outside surface of the items are flushed with nitrogen. The cartridges are held for 1 hour after removal from the flushed canister before they are placed in the test chamber of the MS-17UFT leak detector. This time is called the waiting time and 1 hour is used for most cartridges. The waiting time is another variable that determines leak point settings.

Leak Point Setting:

The MS-17UFT leak tester has a leak indicator which indicates the amount of helium leaking from the cartridge. Since the leak indicator converts the reading from helium to cc · atm/sec of air, each cartridge must have its own leak reject point setting. The fine leak reject point setting is determined by three variables. These are the free volume of the cartridge, the helium pressurizing (bombing) time of the cartridge in the canister, and the waiting time. The helium pressure is at 1 atmosphere gauge.

To calculate the free volume, the volume of the empty case propellant chamber and the volume of the propellant must be calculated. The propellant volume calculated is the volume of the propellant loaded in the case propellant chamber. The free volume is the difference between the cartridge case propellant chamber volume and the volume of the loaded propellant and hardware inside propellant chamber.

Having a constant pressurizing time (1 hour), a constant pressure, and a constant leak rate, two given cartridges will absorb the same amount of helium. A cartridge with a small free volume will have a larger percentage of helium than a cartridge with a larger free volume if both cartridges are subject to the same conditions. Therefore, a cartridge with a large free volume needs a more sensitive leak reject point setting than a cartridge containing a smaller free volume and having the same leak rate.

To calculate a leak reject point setting for a given cartridge that is equivalent to 1 X 10^{-5} cc · atm/sec air, the following equation is used.

$$R_{air} = \frac{LP_L}{P_0}\left[1 - e^{-\frac{L\tau}{VP_0}\left(\frac{M/A}{M}\right)^{1/2}}\right]\left[e^{-\frac{L\theta}{VP_0}\left(\frac{M/A}{M}\right)^{1/2}}\right]$$

where

R_{air} = indicated air leak rate to use on leak indicator (cc · atm/sec air)
L = standard air leak rate at 1 atmosphere (cc/sec)
P_L = helium pressure used (atm)
P_0 = atmosphere pressure (1 atm)
τ = helium pressurizing time (sec)
M/A = molecular weight of air (28.967 lb/mole)
V = free volume of cartridge (cc)
M = molecular weight of tracer gas (helium) (4.003 lb/mole)
θ = waiting time between helium pressurizing time and leak testing (sec)

The values of the parameters used by the Test Branch are given below:

$L = 1 \times 10^{-5}$ cc · atm/sec air at 1 atm
$P_I = 2$ atm
$P_0 = 1$ atm
$\tau = 3600$ sec
$\theta = 3600$ sec

The equation is well suited to programming on a computer in parametric form. Results for R_{air} have been tabulated and are presented in Tables I, II, and III using the following values for free volume as shown on the tables:

(1) Values for θ ranged from 1 min to 1 hr. L, V, and P_E remained constant.

(2) Values for τ ranged from 30 min to 24 hr: L, V, and P_I remained constant.

The derivation of the equation is based on molecular flow both in and out of the device, which is the best approximation for small leaks. A systematic deviation is presented in Appendix A. General conclusions which are based on the final mathematical expression are given below:

(1) The higher the helium pressure, the less the test sensitivity.

(2) The longer the helium pressurizing time, the less the test sensitivity.

(3) The smaller the internal volume, the less the test sensitivity.

Cartridge Leak Test:

The MS-17UFT Leak Test Station is used to detect leaks in cartridges that leak at a rate of greater than 10^{-5} cc/sec of air. The leak reject point setting for each cartridge is equal to 10^{-5} cc/sec of air as the rate has been converted from cc/sec of helium to cc/sec of air by an electrometer inside the tester.

The cartridge to be leak tested is placed in the test chamber of the calibrated leak tester. The calculated leak reject point is set on the tester by adjusting the leak indicator. If the amount of helium escaping from the cartridges is greater than the acceptable amount as set on the indicator, the leak indicator light will go on. The helium escaping from the cartridge under vacuum is read by the spectrometer tube (Figure 2).

Table I

BOMBING TIMES VERSUS MACHINE SETTINGS FOR CARTRIDGE MK 35 MOD 0 LEAK INDICATOR SETTINGS (R_{AIR})

Free volume 12.740 cc
Standard leak rate 0.00001 cc air-atom/sec
Bombing pressure 2 atm abs
Holding pressure - 1 atm abs

Waiting time	Bombing time								
	30 Min	1 Hr	2 Hr	3 Hr	5 Hr	8 Hr	12 Hr	18 Hr	24 Hr
1 Min	7.59E-8	1.51E-7	3.02E-7	4.51E-7	7.46E-7	1.18E-6	1.74E-6	2.56E-6	3.33E-6
5 Min	7.58E-8	1.51E-7	3.02E-7	4.51E-7	7.45E-7	1.18E-6	1.74E-6	2.56E-6	3.33E-6
10 Min	7.58E-8	1.51E-7	3.01E-7	4.50E-7	7.45E-7	1.18E-6	1.74E-6	2.55E-6	3.33E-6
15 Min	7.57E-8	1.51E-7	3.01E-7	4.50E-7	7.44E-7	1.18E-6	1.74E-6	2.55E-6	3.33E-6
20 Min	7.57E-8	1.51E-7	3.01E-7	4.50E-7	7.44E-7	1.18E-6	1.74E-6	2.55E-6	3.33E-6
25 Min	7.56E-8	1.51E-7	3.01E-7	4.49E-7	7.44E-7	1.18E-6	1.74E-6	2.55E-6	3.32E-6
30 Min	7.56E-8	1.51E-7	3.01E-7	4.49E-7	7.43E-7	1.18E-6	1.74E-6	2.55E-6	3.32E-6
40 Min	7.55E-8	1.51E-7	3.00E-7	4.49E-7	7.42E-7	1.17E-6	1.73E-6	2.54E-6	3.32E-6
50 Min	7.54E-8	1.50E-7	3.00E-7	4.48E-7	7.41E-7	1.17E-6	1.73E-6	2.54E-6	3.31E-6
1 Hr	7.53E-8	1.50E-7	2.99E-7	4.47E-7	7.40E-7	1.17E-6	1.73E-6	2.54E-6	3.31E-6

Table II

BOMBING TIMES VERSUS MACHINE SETTINGS FOR CARTRIDGE MK 18 MOD 0 LEAK INDICATOR SETTINGS (R_{AIR})

Free volume 139 000 cc
Standard leak rate 0.00001 cc air-atom/sec
Bombing pressure 2 atm abs
Holding pressure - 1 atm abs

Waiting time	Bombing time								
	30 Min	1 Hr	2 Hr	3 Hr	5 Hr	8 Hr	12 Hr	18 Hr	24 Hr
1 Min	6.97E-9	1.39E-8	2.78E-8	4.18E-8	6.95E-8	1.11E-7	1.67E-7	2.49E-7	3.32E-7
5 Min	6.96E-9	1.39E-8	2.78E-8	4.18E-8	6.95E-8	1.11E-7	1.66E-7	2.49E-7	3.32E-7
10 Min	6.96E-9	1.39E-8	2.78E-8	4.18E-8	6.95E-8	1.11E-7	1.66E-7	2.49E-7	3.32E-7
15 Min	6.95E-9	1.39E-8	2.78E-8	4.18E-8	6.95E-8	1.11E-7	1.66E-7	2.49E-7	3.32E-7
20 Min	6.96E-9	1.39E-8	2.78E-8	4.17E-8	6.95E-8	1.11E-7	1.66E-7	2.49E-7	3.32E-7
25 Min	6.96E-9	1.39E-8	2.78E-8	4.17E-8	6.95E-8	1.11E-7	1.66E-7	2.49E-7	3.32E-7
30 Min	6.96E-9	1.39E-8	2.78E-8	4.17E-8	6.95E-8	1.11E-7	1.66E-7	2.49E-7	3.32E-7
40 Min	6.96E-9	1.39E-8	2.78E-8	4.17E-8	6.95E-8	1.11E-7	1.66E-7	2.49E-7	3.31E-7
50 Min	6.96E-9	1.39E-8	2.78E-8	4.17E-8	6.95E-8	1.11E-7	1.66E-7	2.49E-7	3.31E-7
1 Hr	6.97E-9	1.39E-8	2.78E-8	4.18E-8	6.95E-8	1.11E-7	1.67E-7	2.49E-7	3.32E-7

Table III

BOMBING TIMES VERSUS MACHINE SETTINGS FOR
CARTRIDGE MK 3 MOD 0 LEAK INDICATOR SETTING (R_{AIR})

Free volume = 1.038 cc
Standard leak rate = 0.00001 cc air-atom/sec
Bombing pressure = 2 atm abs
Holding pressure = 1 atm abs

Waiting time	Bombing time								
	30 Min	1 Hr	2 Hr	3 Hr	5 Hr	8 Hr	12 Hr	18 Hr	24 Hr
1 Min	9.10E-7	1.78E-6	3.40E-6	4.87E-6	7.44E-6	1.05E-5	1.35E-5	1.62E-5	1.78E-5
5 Min	9.04E-7	1.77E-6	3.38E-6	4.84E-6	7.40E-6	1.04E-5	1.34E-5	1.61E-5	1.77E-5
10 Min	8.97E-7	1.75E-6	3.35E-6	4.81E-6	7.34E-6	1.04E-5	1.33E-5	1.60E-5	1.76E-5
15 Min	8.91E-7	1.74E-6	3.33E-6	4.77E-6	7.28E-6	1.03E-5	1.32E-5	1.59E-5	1.75E-5
20 Min	8.84E-7	1.73E-6	3.30E-6	4.73E-6	7.23E-6	1.02E-5	1.31E-5	1.58E-5	1.73E-5
25 Min	8.77E-7	1.71E-6	3.27E-6	4.70E-6	7.17E-6	1.01E-5	1.30E-5	1.56E-5	1.72E-5
30 Min	8.70E-7	1.70E-6	3.25E-6	4.66E-6	7.12E-6	1.00E-6	1.29E-5	1.55E-5	1.71E-5
40 Min	8.57E-7	1.67E-6	3.20E-6	4.59E-6	7.01E-6	9.88E-6	1.27E-5	1.53E-5	1.68E-5
50 Min	8.43E-7	1.65E-6	3.15E-6	4.52E-6	6.90E-6	9.73E-6	1.25E-5	1.51E-5	1.65E-5
1 Hr	8.30E-7	1.62E-6	3.10E-6	4.45E-6	6.79E-6	9.58E-6	1.23E-5	1.48E-5	1.63E-5

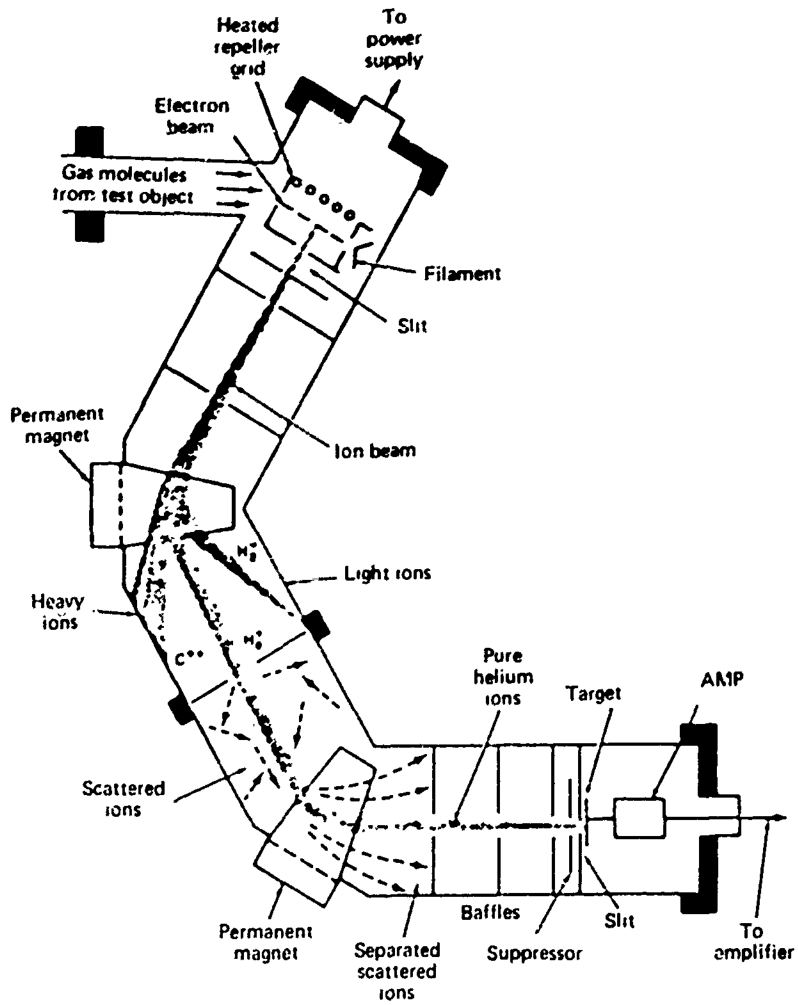

FIGURE 2. MASS SPECTROMETER TUBE (CEE-TUBE)

The operation of the MS-17UFT spectrometer tube is divided into three functional parts: ion production, ion separation, and ion collection. Since neutral atoms and molecules of a gas cannot be separated by a magnetic mass spectrometer, they must first be converted to positively charged ions. This conversion is accomplished by the ion source of the tester. Inside the ion source there is a tungsten filament which is heated by passing an electric current through it. The hot filament emits a regulated beam of electrons which collide with the atoms and molecules of the gas in the spectrometer tube. The electrons of the gas in the mass spectrometer are removed from the atoms and molecules of the gas as the electrons collide with the source of electrons from the tungsten filament. These collisions produce positive ions which encounter the electrostatic fields established within the source.

Since the gas entering the spectrometer tube contains atoms and molecules of different kinds, the ion beam will contain a variety of ions from the atmosphere and will contain helium if a leak is found in the cartridge. A magnetic analyzer separates the helium ions from the remainder of the ion beam and passes these ions on to a detector. Two magnets acting as repeliers are outside the vacuum system and set up magnetic fields perpendicular to the ion beam. The magnetic fields cause the paths of the ions to be bent with the amount of bending dependent on the mass of the given ion. In the first magnet, the arrangement is such that only helium has the right mass to pass through the magnetic sector and through the opening in the baffle on the other side. Most of the other ions will be deflected too much or too little and will be intercepted by the baffle between the two magnets. However, some nonhelium ions may get past the baffle because of scattering within the tube. To eliminate these, a second magnetic field similar to the first accepts helium ions from the nonhelium ions. By means of this arrangement of magnets and baffles, helium will be selectively transmitted to the detector. The helium ions, having travelled the length of the tube, must again travel through baffles and a slit to reach a ground potential. This ground potential is called a target and gives up an electron in order to stabilize the positive charge of the helium ion. The flow of these electrons constitutes a current which is detected and amplified by an electrometer tube located directly within the spectrometer tube. The resultant amplified signal, which is proportional to the amount of helium in the spectrometer tube, appears as a visual indication on the leak indicator meter.

TEST PROCEDURES

Pressurization of Cartridges

The helium-pressurizing station consists of a control panel, helium and nitrogen supply, gauges, and canisters. The control panel has pump switches which turn on the nitrogen and helium regulators which supply nitrogen or helium to the canisters. A supply of nitrogen and helium is contained in nitrogen and helium regulators. The regulators are connected to the compound gauges by a metal tube. The compound gauges give the pressure readings of the canisters which are clamped to the gauges.

(1) Turn on nitrogen and helium regulators.

(2) Remove each canister from gauge and vent each canister by the manual valves on the underside of the canister.

(3) Check each cartridge for identification.

(4) Place the cartridge in the canister.

(5) Place helium/nitrogen switch in nitrogen pump position.

(6) Depressurize canister until gauge reads minus 30. Minus 30 on gauge means zero atmosphere pressure (vacuum conditions).

(7) Turn off the nitrogen switch when gauge reads zero atmosphere.

(8) Turn on the helium switch on the control panel.

(9) Pressurize the canister to plus 15 on the gauges. Plus 15 is a pressure reading of 2 atmospheres.

(10) Turn off the helium switch and make sure the helium/nitrogen switch is turned off.

(11) Leave the cartridge in the canister for 1 hour at this pressure.

(12) Vent canister.

(13) Remove the test items (cartridges).

(14) The cartridge must remain in normal atmospheres for 1 hour after removal from canister.

Test Equipment Calibration

(1) Plug in power cable of the MS-17UFT Leak Test Station.

(2) Connect leak indicator to a black box on the back of the leak indicator. The black box is connected to an amplifier in the test unit. The amplifier is at the end of the spectrometer tube

(3) Connect compressed air supply

(4) Turn on roughing pump circuit breaker.

(5) Turn on fore pump circuit breaker

(6) After the fore pump stops gurgling (5 minutes), turn on diffusion pump circuit breaker.

(7) After a 20 minute wait, turn on electronics circuit breaker.

(8) Add liquid nitrogen to a cold trap in the MS-17UFT tester. The liquid nitrogen is poured in by use of a funnel and an insulated decanter.

(9) Turn on the Filament On switch and the No Emission lamp on the leak indicator box will go off.

(10) Close the test chamber trap door and hold it shut while pressing the roughing valve switch. Hold the roughing switch for at least 20 seconds and then release switch.

(11) Press test valve switch.

(12) Press Auto Mode switch; test chamber door will spring open.

An SC-4 sensitivity calibrator is used to determine the sensitivity of the MS-17UFT tester. The SC-4 calibrator is backfilled with helium around an evacuated tube inside the probe. The SC-4 calibrator has a set leak rate and is connected to the test chamber. If the leak indicator has a reading matching the leak rate of the SC-4 calibrator, then the leak tester is working correctly.

(13) Before using the SC-4 calibrator, turn on the manual switch and place SC-4 calibrator on the test cup of the test chamber. Open roughing valve switch and hold trap door for 20 seconds. Check leak indicator reading to see if it matches the set leak rate of the SC-4 calibrator.

If the leak indicator reading does not match the set leak rate, the leak tester must be tuned to increase the sensitivity of the leak tester.

(14) Place the mode switch in manual.

(15) Turn filament off and set the leak indicator reading to zero by adjusting the zero set control.

(16) Press the vent switch to vent the test cup of the test chamber and then release.

(17) Place the SC-4 calibrator on the test cup and press the roughing valve switch for 20 seconds and release the switch.

(18) Activate test valve switch. If while in this position, high pressure caused by leaks is introduced to the leak detector, the filament will be turned off and the no emission light will light. To correct this situation, press the roughing valve switch for 20 seconds and then release. Turn on the filament and if it remains on, proceed with the leak tester tuning.

(19) Adjust the emission control until the emission is 3MA.

(20) Set both ion focus and ion center controls halfway between their zero and maximum positions.

(21) Turn the repeller control three-fourths turn in counterclockwise direction.

(22) Slowly move peak tune control counterclockwise until leak indicator scale has the same reading as the leak rate indicated on the SC-4 calibrator.

(23) Remove SC-4 calibrator from the test cup.

(24) Close the test valve by switching to auto mode and then back to manual.

Cartridge Test

(1) After the leak tester has been checked for sensitivity, depress the fine leak reject button atop the leak indicator, and adjust the reject point to the desired reject point value with the fine leak reject adjust control (located on rear panel of leak indicator box).

(2) Place cartridge in the test chamber box of the leak detector.

(3) Set leak reject point. Turn the scale adjuster knob to desired value; depress fine leak reject point setting; set the reject point to the desired value with the fine leak reject adjust control (located on rear panel of leak indicator box).

If the cartridge has a leak greater than the fine leak reject point setting on the leak indicator, the fine leak or gross leak button will light up. If the cartridge leak is greater than the reject point scale setting, then the cartridge has failed the test. If the leak is less than the reject point setting, the cartridge has passed the test.

Appendix A

MATHEMATICAL DEVELOPMENT

Leak testing consists of three stages. The initial stage involves the application of a tracer gas (helium) at high pressure, to the external surfaces of the cartridge. If a leak exists, tracer gas flows into the cartridge and the partial pressure increases. The mathematical model is given below.

Pure molecular flow is assumed as it is necessary to detect leaks down to 10^{-7} cc/sec of air, while leaks as high as 10^{-3} cc/sec of air may still show molecular flow characteristics. The basic equation for molecular flow is

$$VdP/dt = (T/M)^{1/2} \cdot (\Delta p) \tag{1}$$

where

V = free volume of test specimen (cartridge) (cc)
P = partial pressure of helium in the cartridge (atm)
t = time (sec)
T = temperature (°R)
M = molecular weight of tracer gas (lb/mole)
Δp = pressure differential of tracer gas across the leak (atm).

During the helium pressuring phase, the external tracer gas pressure, P_E, is held constant for a selected time period. Equation (1) can be rewritten

$$dP/dt = C \cdot 1/V(T/M)^{1/2} \cdot (P_E - P) \tag{2}$$

where

C = proportionality constant
P_E = external tracer gas absolute pressure (atm).

Incorporating the absolute temperature into the constant

$$K = C \cdot (T)^{1/2}$$

$$\frac{-dP}{P_E - P} = \frac{-K}{V(M)^{1/2}} \cdot dt \tag{3}$$

Integrating between limits:

$$\ln(P_F - P)\Big|_0^{P_1} = \frac{-K(t)}{V(M)^{1/2}}\Big|_0^{\tau} \qquad (4)$$

$$\ln\frac{P_F - P}{P_F} = \frac{-K\tau}{V(M)^{1/2}} \qquad (5)$$

$$P_1 = P_F\left[1 - e^{\frac{-K\tau}{V(M)^{1/2}}}\right] \qquad (6)$$

where

τ = helium pressurizing time
P_1 = partial pressure of the tracer gas in the cartridge at end of τ.

The second stage consists of releasing external gas pressure during which some tracer gas is lost from the cartridge.

$$\frac{dP}{dt} = -\frac{K}{V(M)^{1/2}}P \qquad (7)$$

The negative sign indicates that tracer gas is being lost from the cartridge.

Integrating between limits

$$\ln P\Big|_{P_1}^{P_2} = \frac{-K}{V(M)^{1/2}}t\Big|_0^{\theta} \qquad (8)$$

$$P_2 = P_1 e^{-\frac{K\theta}{V(M)^{1/2}}} \qquad (9)$$

Where

θ = waiting time between gas pressurizing phase and leak testing (sec)
P_2 = partial pressure of tracer gas in the cartridge at end of waiting time (atm).

Substituting equation (6) into equation (9) yields:

$$P_2 = P_F \left[1 - e^{\frac{-K\tau}{V(M)^{1/2}}}\right]\left[e^{\frac{-K\theta}{V(M)^{1/2}}}\right] \tag{10}$$

The last stage involves the leak test which by definition is carried out at a tracer gas partial pressure P_2. The leak rate is:

$$R = -V(dP/dt) \text{ at } P = P_2$$

$$R = -V\left(\frac{-K}{V(M)^{1/2}}\right) P_2 = \frac{KP_2}{(M)^{1/2}} \tag{11}$$

where

R = leak rate reading on leak indicator (cc · atm/sec air).

Substituting for P_2 in equation (10):

$$R = \frac{P_F K}{(M)^{1/2}}\left[1 - e^{\frac{-K\tau}{V(M)^{1/2}}}\right]\left[e^{\frac{-K\theta}{V(M)^{1/2}}}\right] \tag{12}$$

At this point it is convenient to define a standard leak size, L. as the flow rate of air through the leak under conditions of one atmosphere air pressure on one side and a vacuum on the other.

$$L = -V\left(\frac{dP}{dt}\right) P = P_0 = -V\left(\frac{-KP_0}{V(M/A)^{1/2}}\right)$$

$$L = \frac{KP_0}{(M/A)^{1/2}} \tag{13}$$

where

L = air leak rate at standard conditions (cc · atm/sec air)
M/A = molecular weight of air (28.967 lb/mole)
P_0 = atmosphere pressure (1 atm)

From equation (13)

$$K = \frac{L(M/A)^{1/2}}{P_0}$$

Substituting this value into equation (12)

$$R_{\text{helium}} = \frac{LP_F}{P_0} \left(\frac{M/A}{M}\right) \left[1 - e^{-\frac{L\tau}{VP_0}\left(\frac{M/A}{M}\right)^{1/2}}\right] \left[e^{-\frac{L\theta}{VP_0}\left(\frac{M/A}{M}\right)^{1/2}}\right] \tag{14}$$

This is the operational equation for the leak detector when it is calibrated for a reading of tracer gas flow. If one calibrates the leak measuring device for air, the appropriate operating equation to be used is

$$R_{\text{air}} = \frac{LP_F}{P_0} \left[1 - e^{-\frac{L\tau}{VP_0}\left(\frac{M/A}{M}\right)^{1/2}}\right] \left[e^{-\frac{L\theta}{VP_0}\left(\frac{M/A}{M}\right)^{1/2}}\right] \quad . \tag{15}$$